

Statistical Typhoon Intensity Prediction Scheme

John Knaff

*CIRA/Colorado State
University*

In Partnership with

Mark DeMaria
NOAA/NESDIS

Introduction

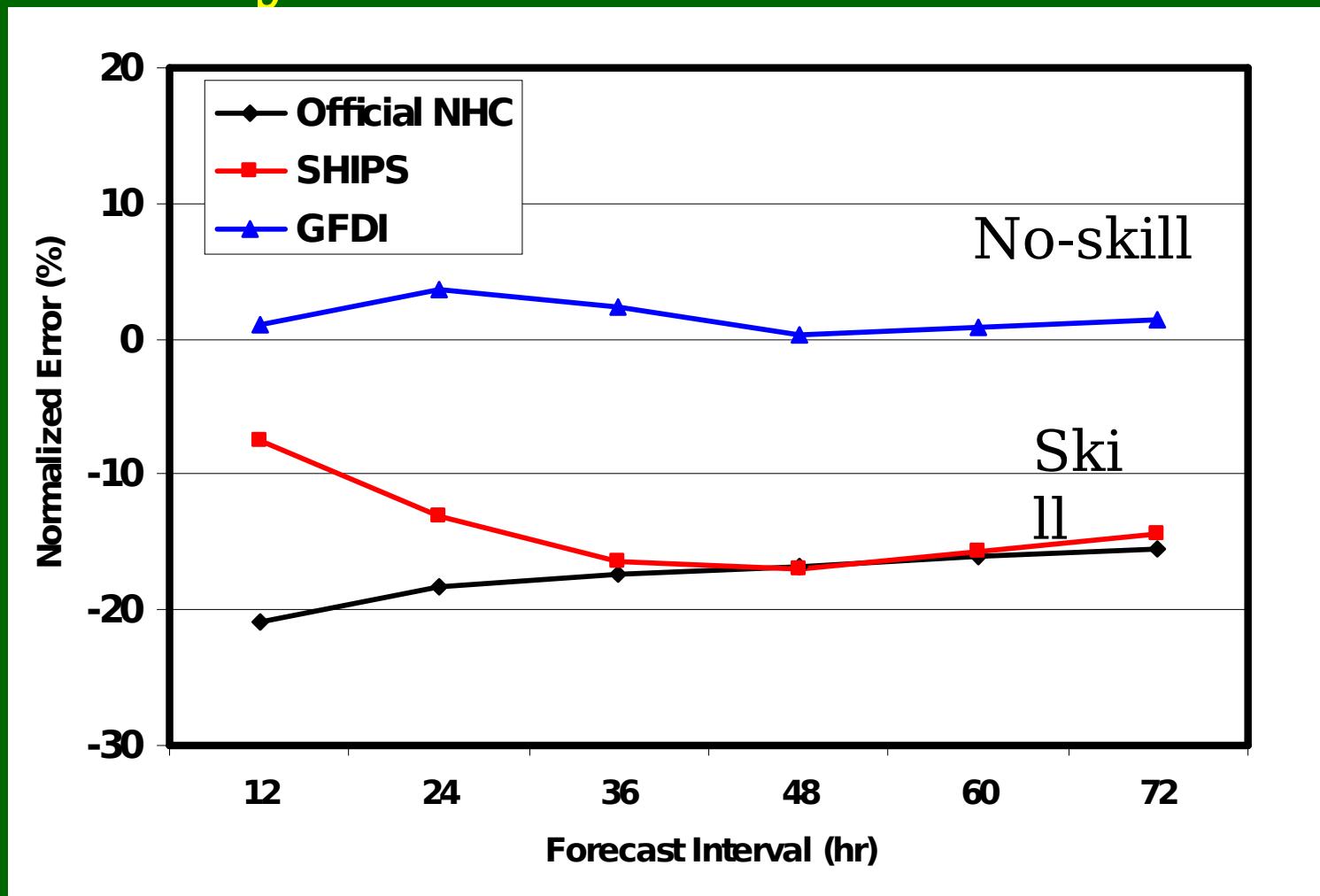
- ONR funded the development of two statistical models to predict tropical cyclone intensity forecasting
 1. 5-day STIFOR for verification and comparison purposes
 2. Statistical Typhoon Intensity Prediction Scheme (Statistical-dynamical)

GOAL

- To quickly (1-year) develop a statistical-dynamical intensity forecast model for use in the western North Pacific
 1. Build on the success of this method in other basins
 2. Give JTWC two more intensity forecasting tools (STIPS/Decay STIPS, ST5D)

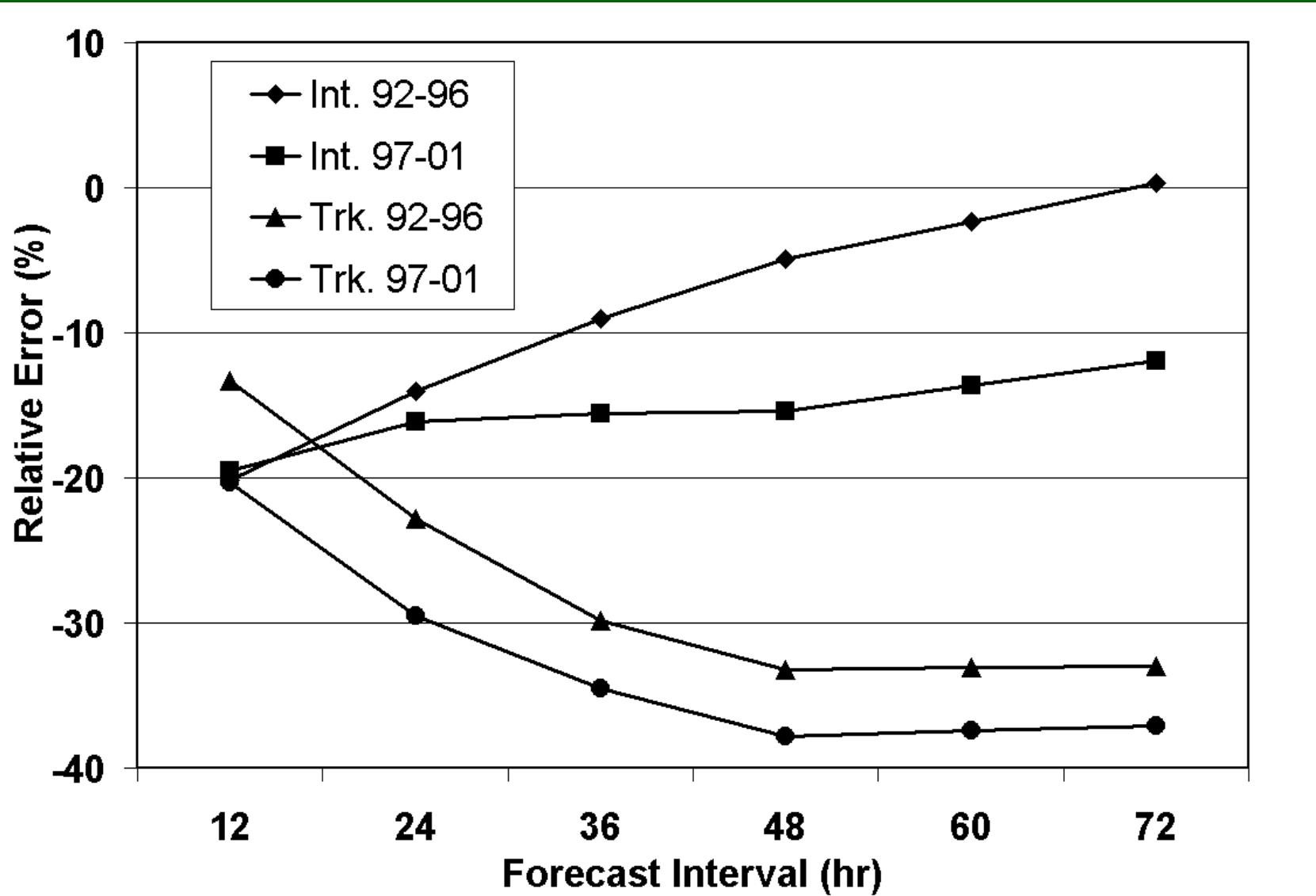
1997-2001 Normalized Intensity Errors*

Early models and official NHC



*Atlantic basin, NHC verification rules, 975 cases at 12h,
544 at 72 h,
errors normalized by SHIFOR errors

NHC Official Track and Intensity Skill over the previous two 5-year periods

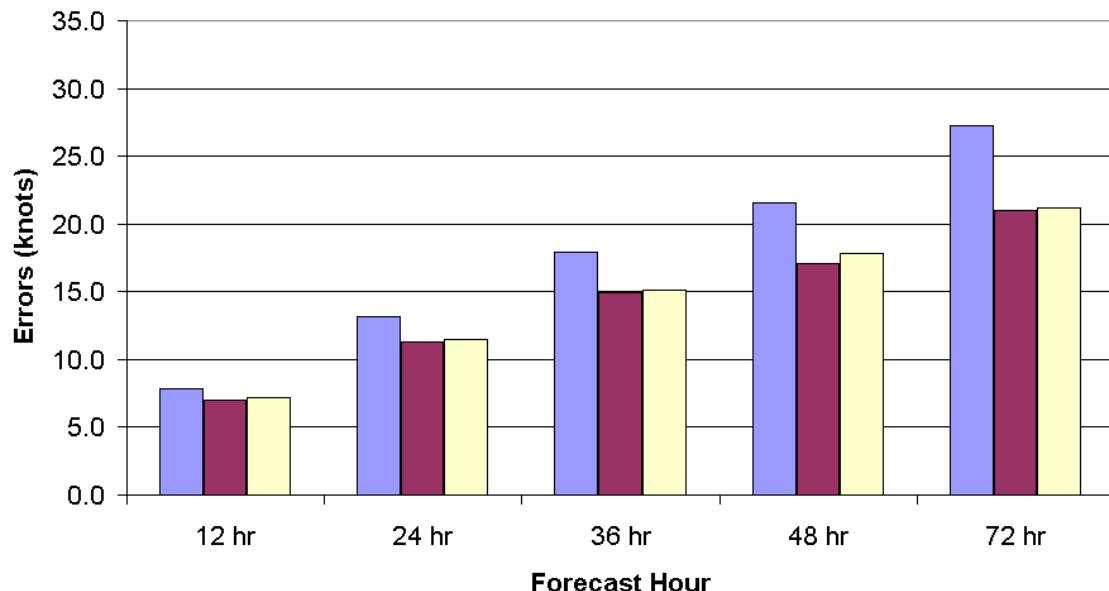


A New Climatology and Persistence model: ST5D vs STIFOR (CLIP)

- Use the change in intensity as the independent variable (predictand) - this is an easier quantity to predict than intensity
- Use quadratic terms in the statistical equations - allows better regression results.
- Makes forecasts through 5 days.

2001 Forecast Errors

CLIP JTWC ST5D

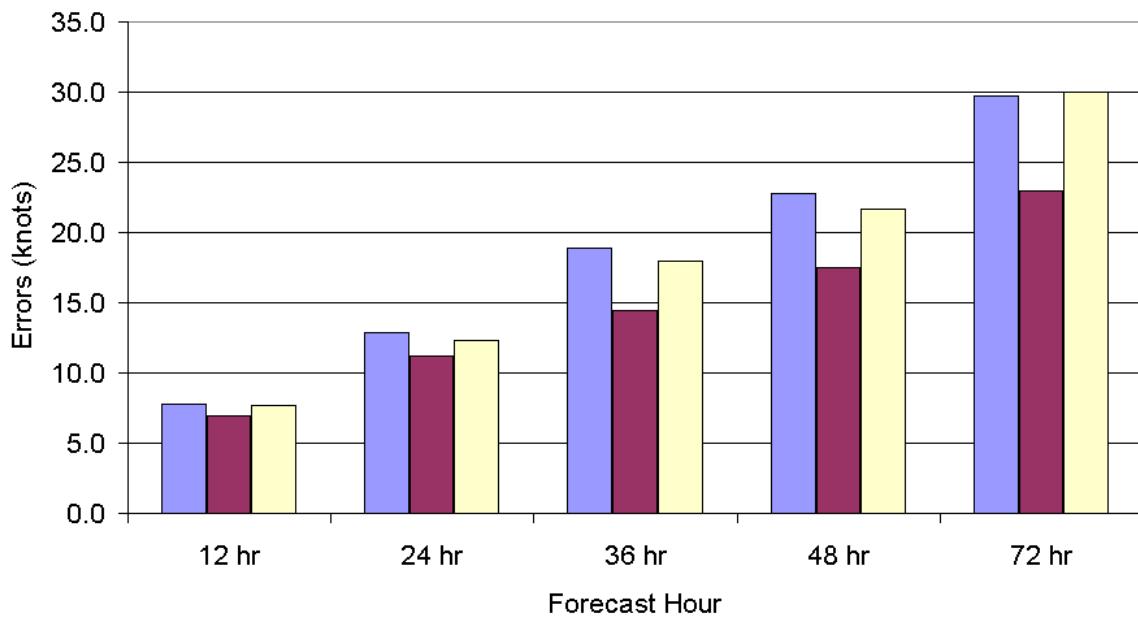


JTWC by a nose

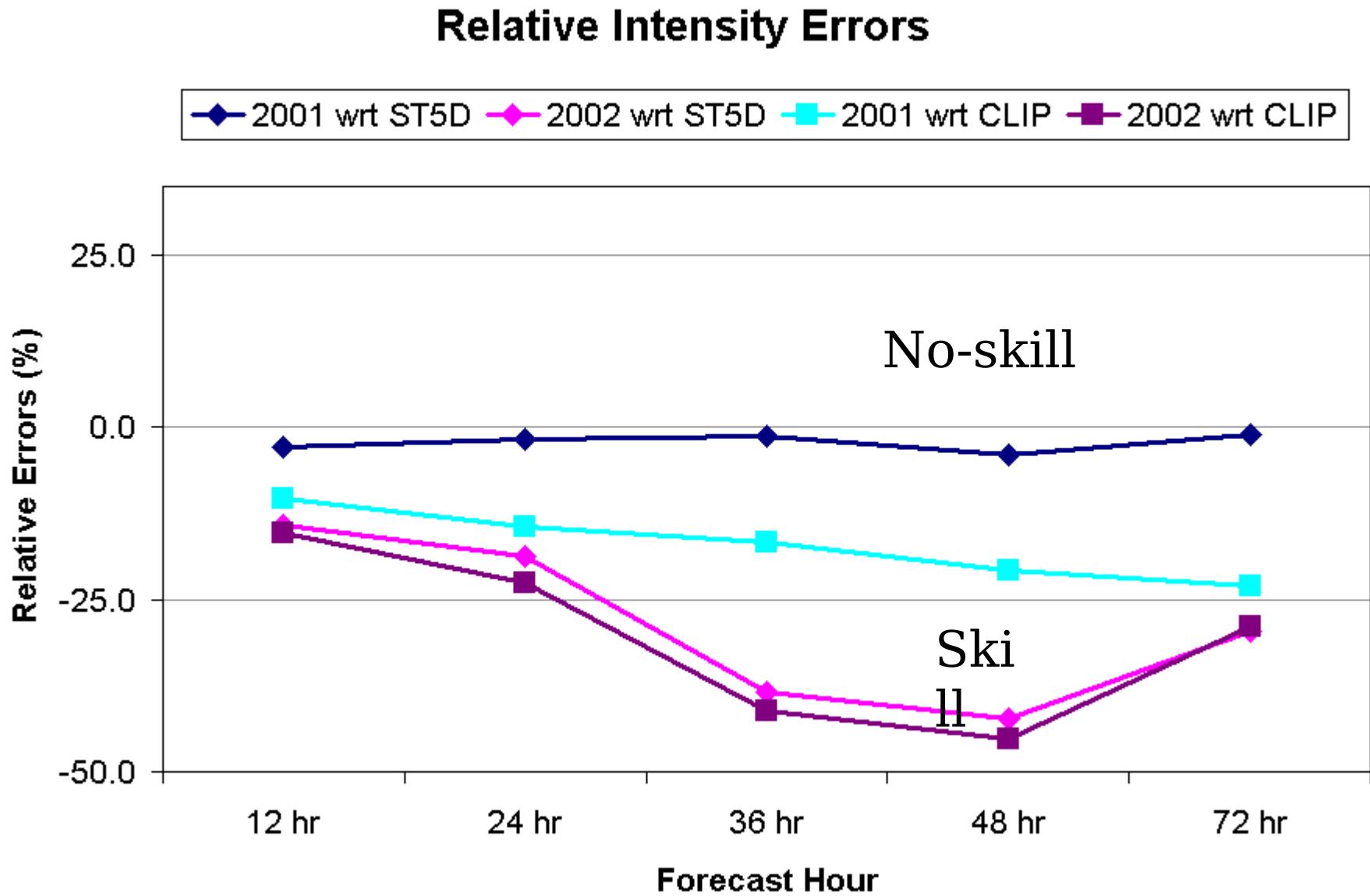
A February Super Typhoon?

2002 Forecast Errors

CLIP JTWC ST5D



Raising the “skill bar”... and the next step?

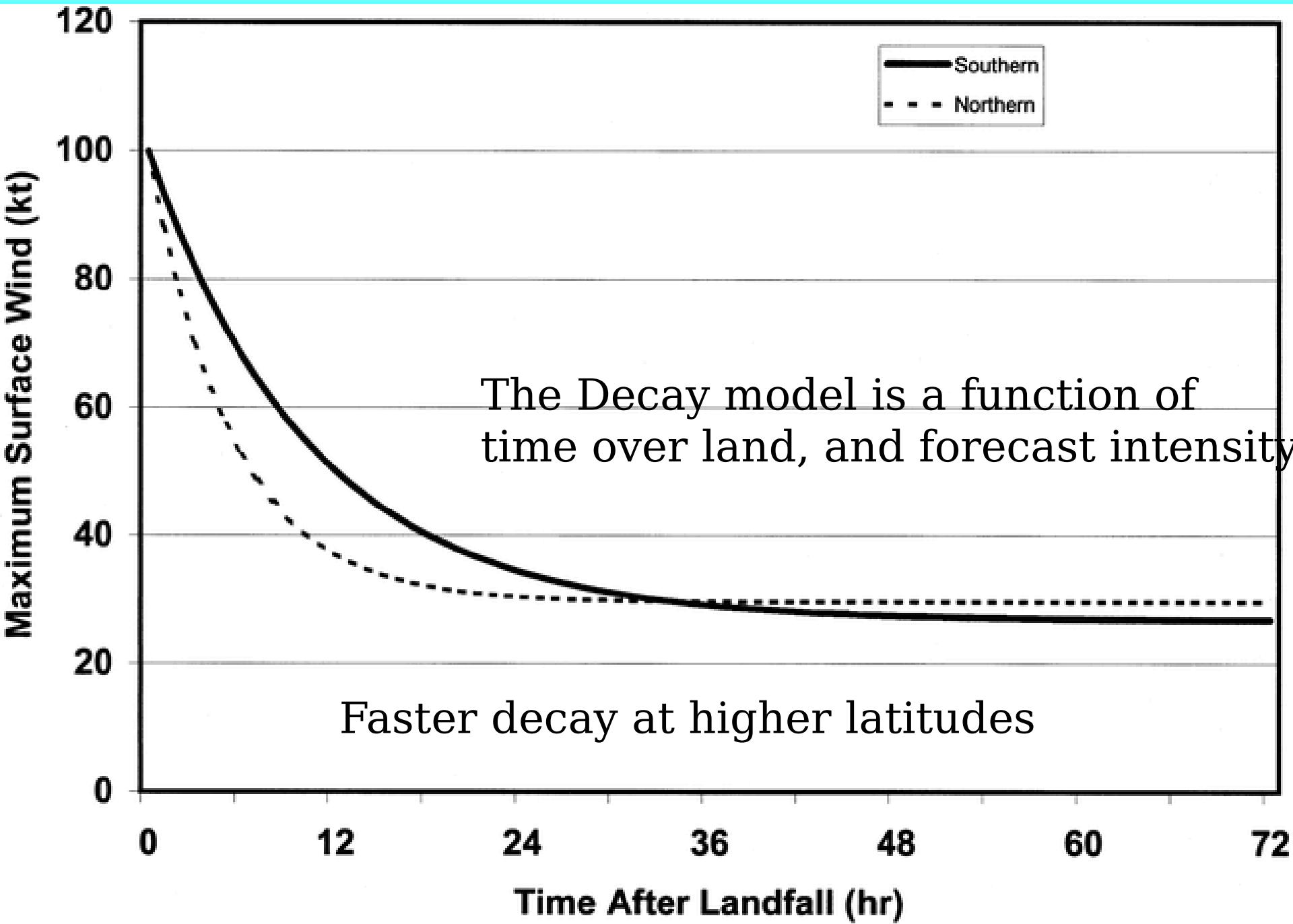


The Premise - STIPS should improve on ST5D because ...

- Takes advantage of synoptic information along a forecast track in addition to climatology and persistence
 - Shear
 - SST
 - Divergence
 - RH

STIPS Model Development

- The STIPS Model has a statistical-dynamical formulation in real-time applications, but was developed using a perfect prognostication assumption.
- In real-time forecasts
 1. analyses of fields are replaced by forecast fields
 2. The best track is replaced by the JTWC forecast
- Inland Decay is handled after the forecast is made
 1. South of 36 N the decay model follows Kaplan and DeMaria (1995)
 2. North of 40 N the decay model follows Kaplan and DeMaria (2001)
 3. Between 36N and 40N a linear weighting of these methods is applied



Datasets

- NOGAPS Analyses – Update Last week through 2001 WHY?
 - July 21,1997 – December 31, 2000 ... now 2001
 - T, U, V, q, ϕ were collected twice daily at 100, 150, 200, 250, 300, 400, 500, 700, 850, 925, and 1000 mb
 - Skin temperature is used for SST
- Best track
 - same time period
- SST Climatology Levetus (1982) was used to fill in missing skin temperature
- Land and ocean was determined using a digitized dataset that contains continents and major Islands

Statistical Formulation

- Multiple linear regression.
- The change in intensity 12-h – 120-h is the independent variable
- 10 equations (12-h through 120-h)
- Two pools of potential predictors were tested
 1. 200 - 850 and 500 - 850 mb shear
 2. Generalized Shear 200 to 850 mb

Potential Predictors

- Climatology and Persistence Factors
- Synoptic Factors

CLIPER Predictors

from stifor5d

Predictor	Description
VMAX	Current Intensity
VMAX ²	Current Intensity square
DVMX	12-hour change in Intensity
JDAY	Absolute value of Julian Day minus 248
SPDX	Zonal Storm Motion

Potential Synoptic Predictors (time averaged along the track)

Predictor	Description
MPI	Maximum Potential Intensity (MPI) - an empirical relationship
MPI^2	MPI^2 squared
$\text{MPI} \times \text{VMAX}$	MPI times the initial intensity
RHLO	Area averaged (200 km to 800 km) relative humidity
RHHI	Area averaged (200 km to 800 km) relative humidity
U200	Area average (200 km to 800 km) zonal wind at 200 hPa
T200	Area average (200 km to 800 km) temperature at 200 hPa
δ_{200}	Area average (0 km to 1000 km) 200 hPa divergence
REFC	Relative Eddy Flux Convergence within 600 km (see Eq 2)
GSHR	Generalized 200 to 850 hPa vertical wind shear (see Eq 3)
SHRS	Area average (200 km to 800 km) 500 hPa to 850 hPa wind shear
SHRD	Area average (200 km to 800 km) 200 hPa to 850 hPa wind shear
$\text{SHRD} \times \text{SIN(LA T)}$	850 hPa to 850 hPa wind shear times the sine of the latitude
$\text{GSHR} \times \text{SIN(LA T)}$	Generalized wind shear times the sine of the latitude
ζ_{850}	Area averaged (0 km to 1000 km) 850 hPa relative vorticity

Generalized Shear

$$\Delta V_{gen} = 4.0 * \sum_{P=850}^{p=200} w_p \sqrt{(u_p - \bar{u})^2 + (v_p - \bar{v})^2}, \text{ where}$$

$$\bar{u} = \sum_{p=850}^{p=200} w_p u_p, \text{ the deep layer zonal wind,}$$

$$\bar{v} = \sum_{p=850}^{p=200} w_p v_p, \text{ the deep layer meridional wind,}$$

w_p are mass weights.

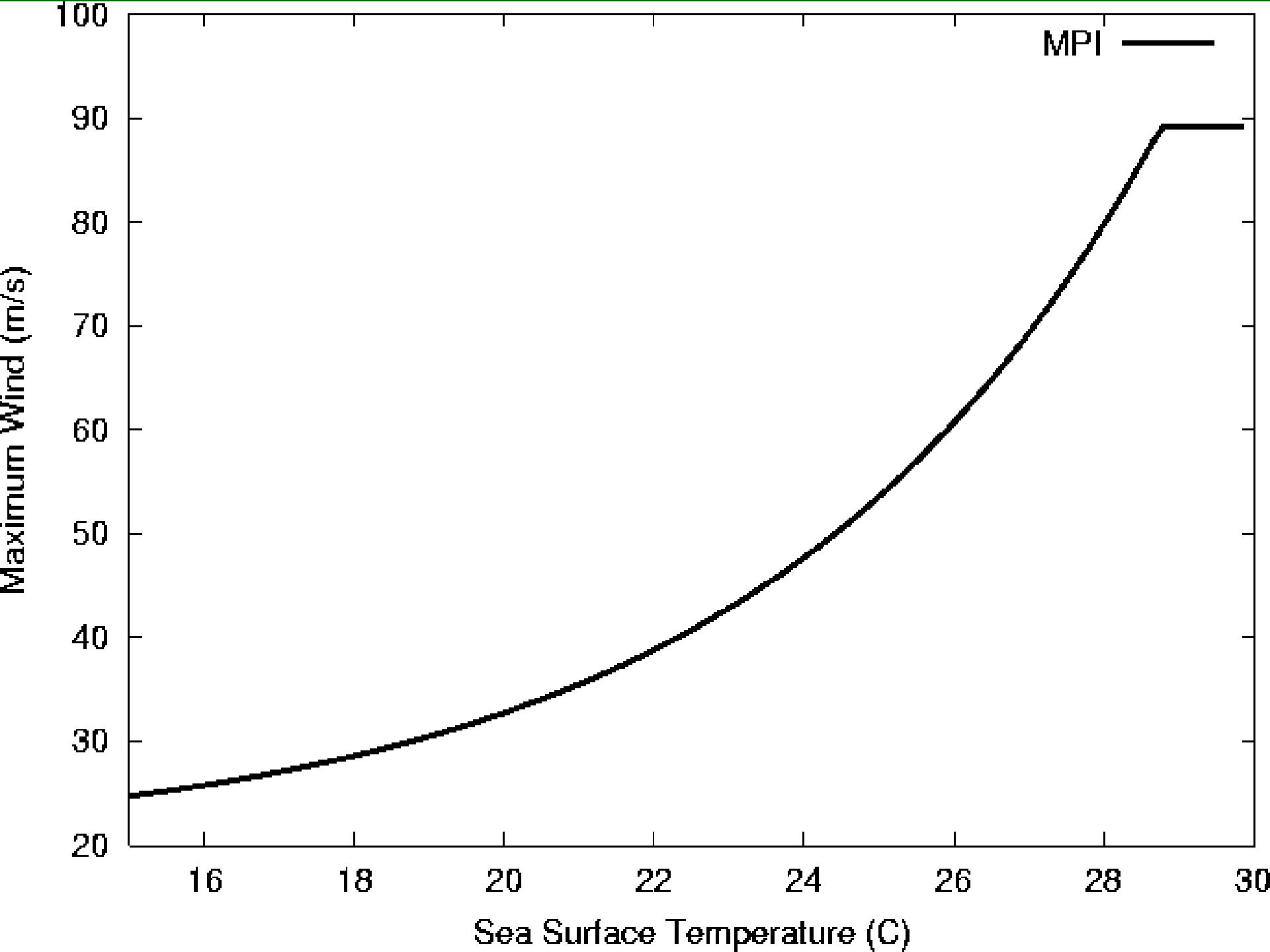
factor of 4.0 makes the values identical for a linear shear p

Maximum Potential Intensity (MPI)

$$MPI = A + Be^{C(T - T_0)}$$

where $A=38.21$, $B=170.72$, $C=0.1909$ and $T_0=30.0$.

Maximum = 173 knots ~ 28.75 C



Relative Eddy Flux Convergence at 200 mb

$$REFC = -r^{-2} \frac{\partial}{\partial r} \left(r^2 \overline{U_L V'_L} \right)$$

Where U (positive outward) is the radial wind, V (positive cyclonic) is the tangential wind, r is radius. Primes indicate deviations from an azimuthal mean, Over bars represent azimuthal means, and the subscript L denotes this calculation is done following the storm.

Statistical Methodology

- Two predictor pools (1.Layered and 2. Generalized shear)
- Independent variable intensity change from $t=0$.
- Stepwise predictor selection procedure is used to pick predictors at times 12-h through 120-h
- Once the selection is complete for all forecast times a combined predictor pool is created and the coefficients are then calculated using all predictors in the combined pool.

Final Combined Pool of 12 predictors

Predictor	Most Important Forecast Hour
1. DVMX (12-h change)	12
2. SPDX (zonal speed)	108
3. VMAX (intensity)	12
4. VMAX ²	12
5. MPI	24
6. MPI ²	24
7. MPI * VMAX	12
8. SHRG (generalized shear)	36
9. SHRG * sin (LAT)	108
10. U200 (200 mb U)	48
11. D200 (200 mb divergence)	24
12. RH (300-500 mb RH)	48

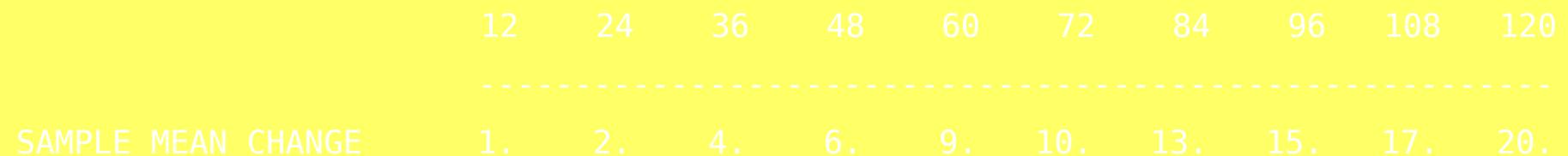
Input from the JTWC

- Through the ATCF
 - Storm Location at $t=0$, $t=-12$
 - Storm intensity and past intensity
 - Forecast Storm track 12 - 120hr

The predictors represent 8 Factors

- Sample Mean Changes
- Combined Intensity Change Potential
 - Combination of 5 predictors (VMAX, VMAX², MPI, MPI²,MPI*VMAX)
- Vertical Shear
 - Combination of 2 predictors (SHRG, SHRG*LAT)
- U200 (in application combined with Vertical Shear)
- Persistence (DVMX)
- 200 mb Divergence
- 300 - 500 mb Relative Humidity
- Storm Motion

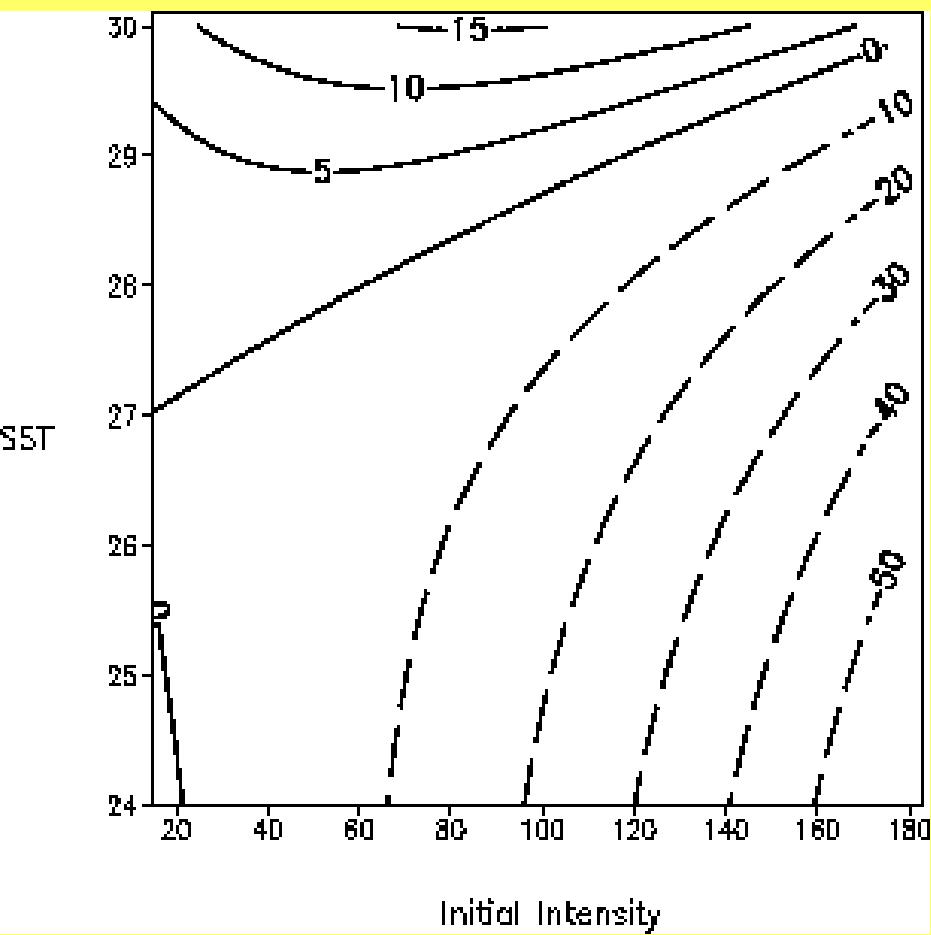
Sample Mean Intensity Change



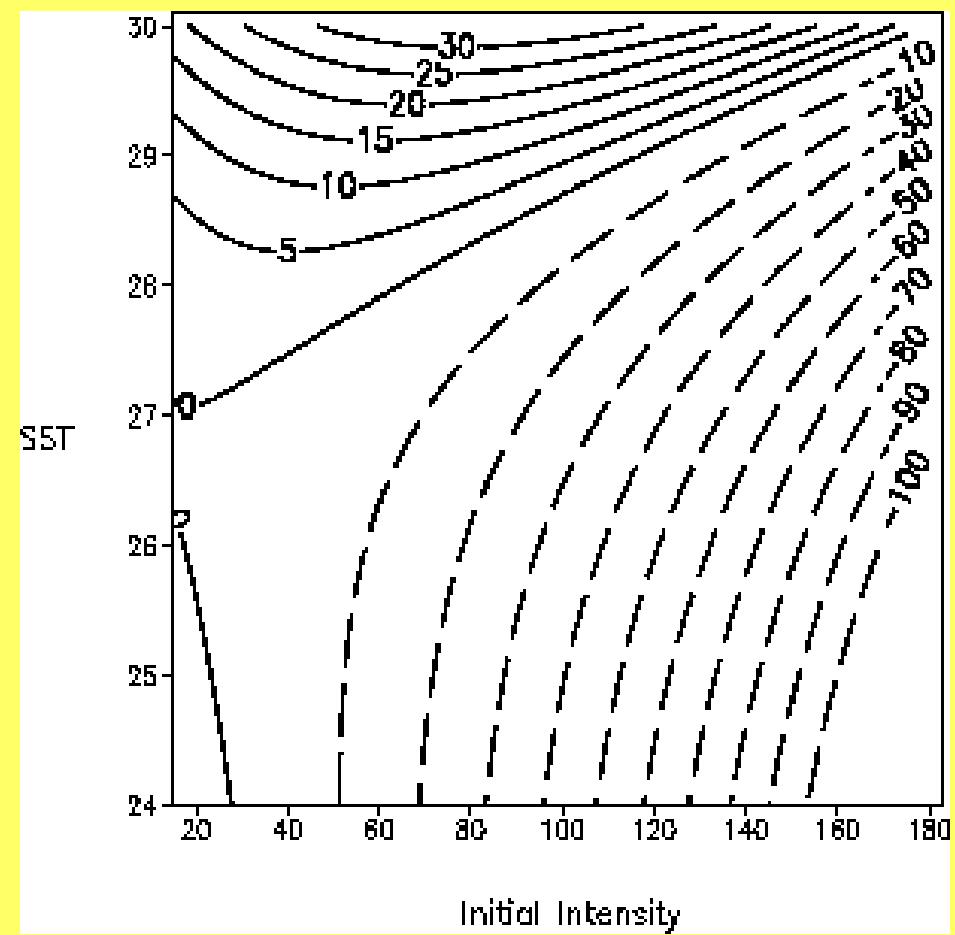
Combined Intensity Changes

Potential

12-h

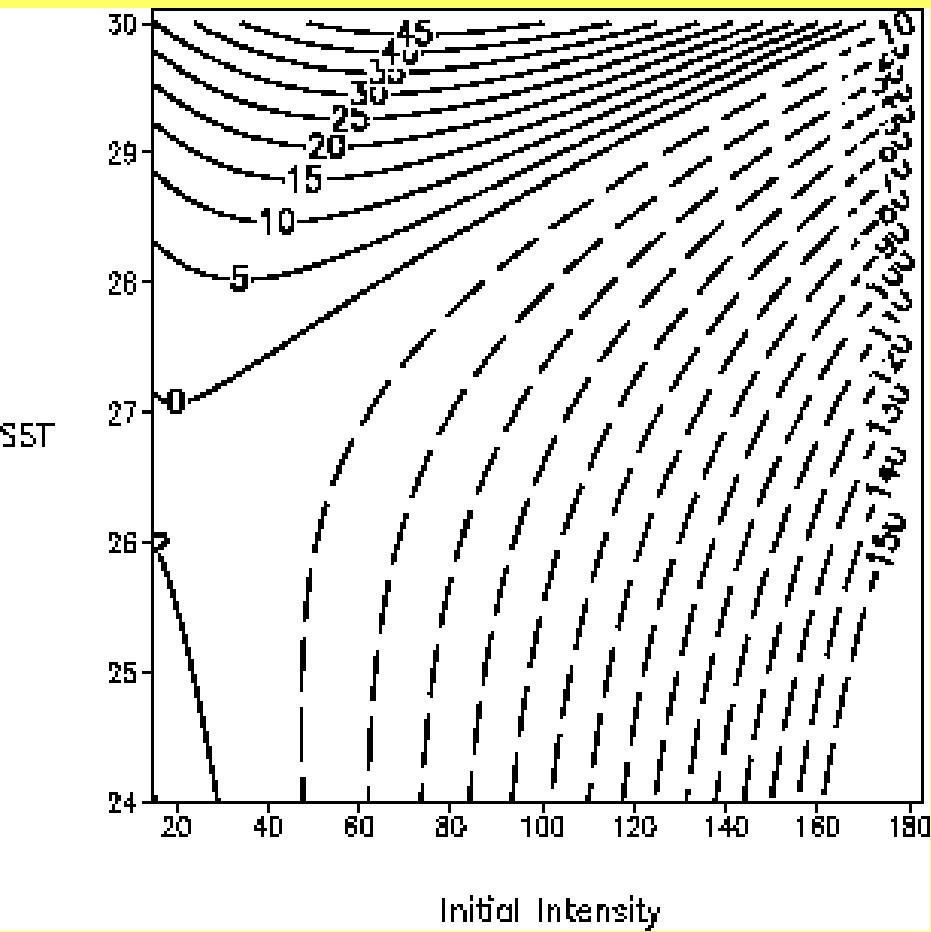


24-h

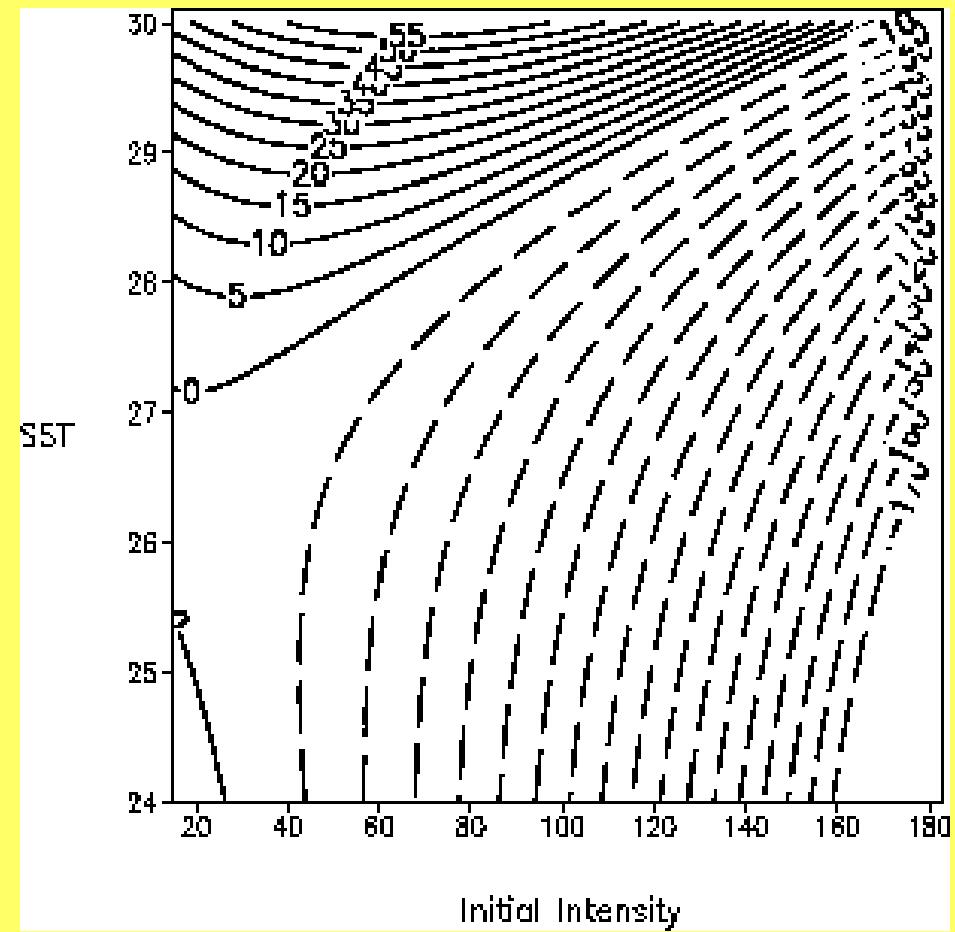


Potential + Mean Change (cont.)

36-h

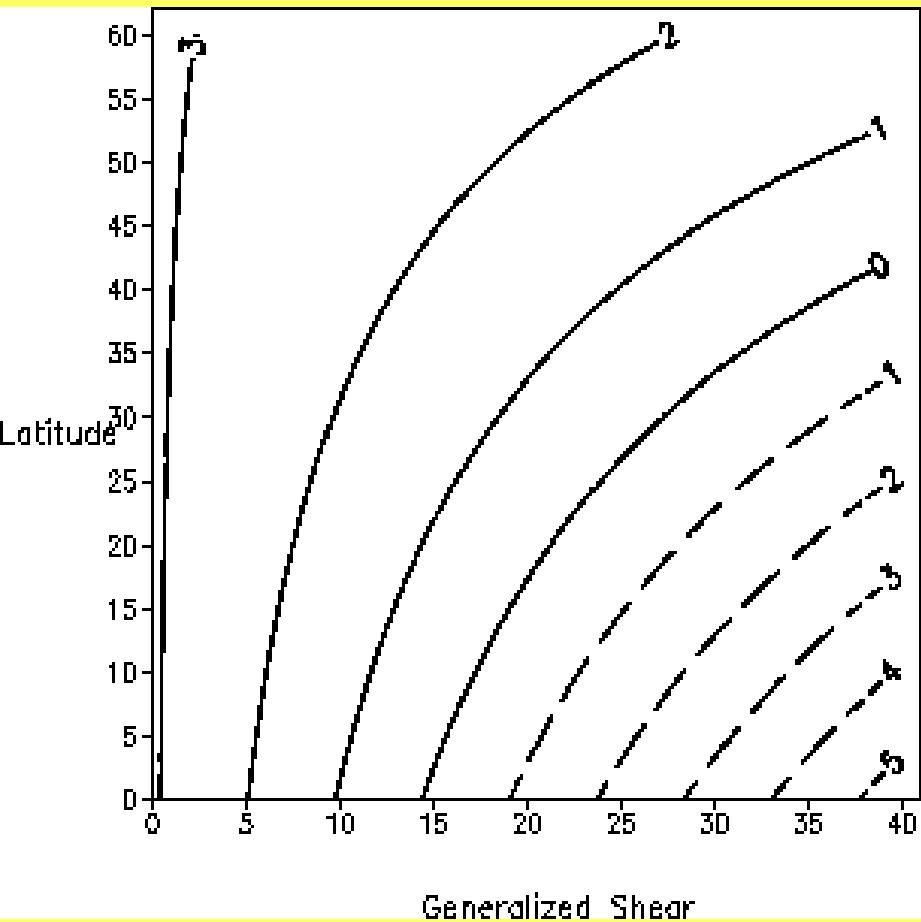


48-h

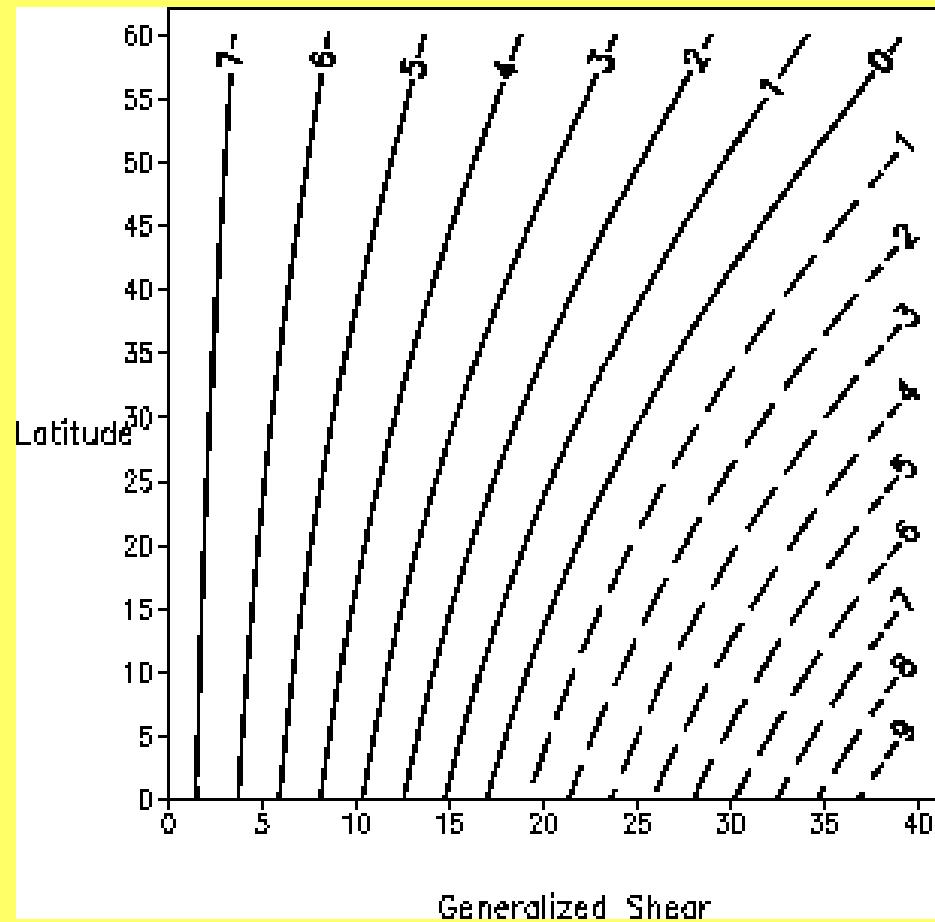


Vertical Shear

12-h



24-h



U200

- Recurvature factor.
 - Favors westerly 200 mb zonal winds
- However, strong positive zonal wind is almost always related to strong vertical wind shear in the developmental data, except at recurvature
- Weak zonal wind along with weak vertical wind shear often indicates a change in the steering flow associated with recurvature.
- Recurvature often is related to intensification (Riehl 1959)
- This term should be considered in combination with the vertical shear terms

Persistence - 12-h Intensity Change

- If intensifying, a storm will continue to intensify
- Most important at 12 hours
- Unimportant after 48 hours

Divergence

- Synoptic scale divergence is important at all times
- Requires about an average value of $6 \times 10^{-6} \text{ s}^{-1}$ in a 1000 km circle for intensification.

300-500 mb Relative Humidity

- important at all times beyond 12-h
- 58% and greater is favored for intensification.

Output

- STIP (STIPS)
- STID (Decay STIPS)
- One page STIPS summary output
- ATCF graphics

5-17-02
12 UTC
Example

Forecast Track Dialog – NONAME wp052002

TAU:

6	12
18	24
30	36
42	48
54	60
66	72
84	96
108	120

Forecast Pos.
 Delete Pos.

TAU (hours)	LAT.	LON.	DIR	SPEED (knots)
0	14.1N	139.5E	315	7
12	14.6N	138.8E	306	4
24	15.4N	138.8E	360	4
36	16.4N	139.1E	16	5
48	17.4N	139.8E	33	6
72	21.0N	142.8E	37	11
96	28.3N	149.6E	38	24
120	34.1N	159.2E	52	25

Help Apply OK Cancel

Intensity Forecast – NONAME wp052002

Intensity Guidance

AID	12h	24h	36h	48h	72h	96h	120h
CONG	60	63	61	62	61	0	0
CONU	67	69	68	69	72	0	0
CON_	69	72	72	72	76	0	0
COSH	70	74	72	70	64	0	0
GFNI	81	84	83	80	77	0	0
ICON	66	69	70	71	72	0	0
JAVI	59	65	61	60	51	40	61
JGSI	61	62	62	64	72	0	0
JGSM	55	60	55	60	70	0	0
JTWC	65	75	75	70	65	70	65
JTWI	65	72	77	80	81	79	81
JTYI	64	70	70	72	79	0	0
JTYM	45	45	50	60	75	0	0
RECR	70	80	90	100	100	0	0
ST5D	67	72	73	75	74	73	64
STID	70	80	89	95	99	78	50
STIP	70	80	89	95	99	78	50

Time–Intensity Graph

Intensity Forecast



Gusts



Help

OK

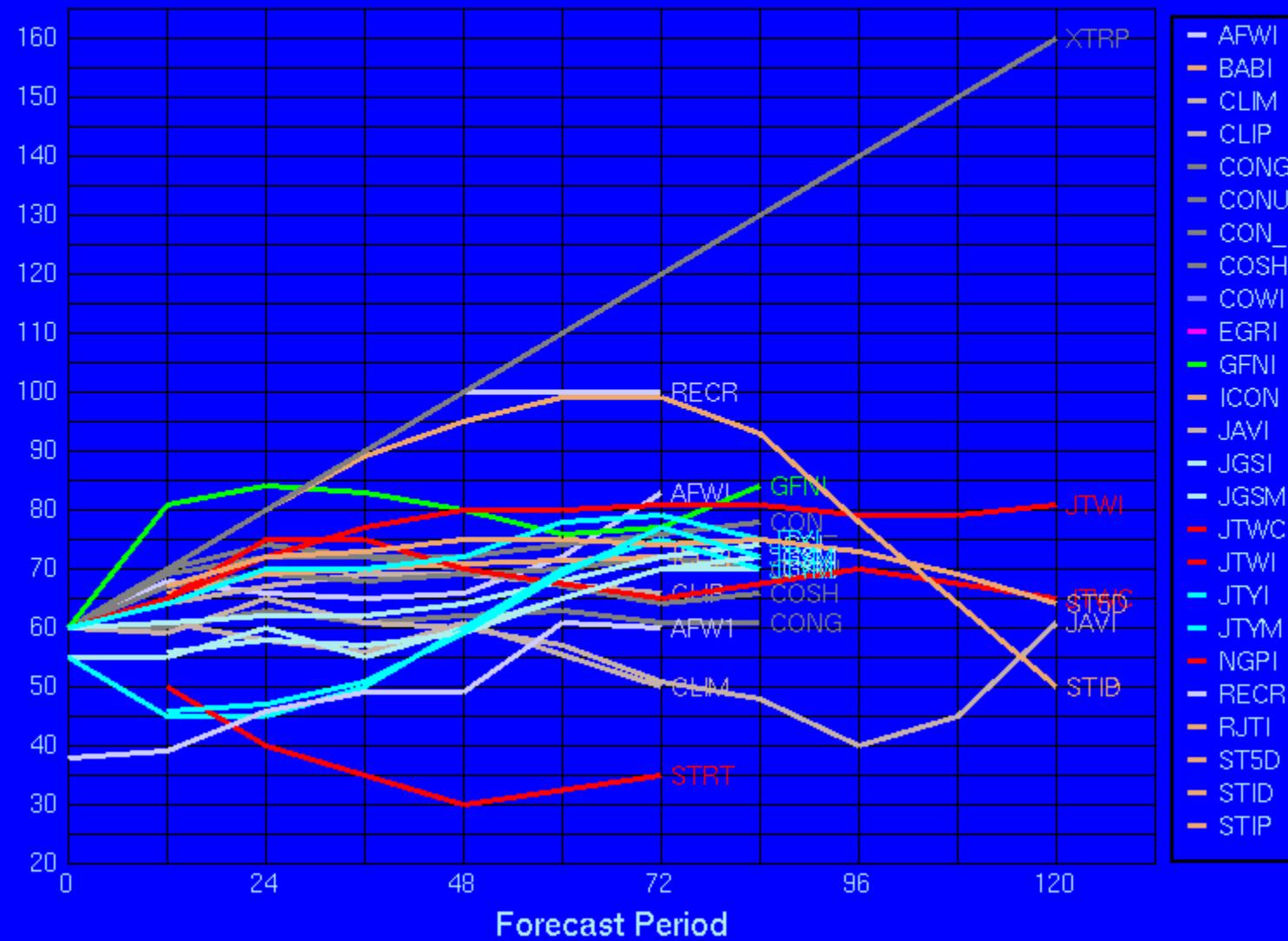
Cancel

ATCF Graph Window – NONAME wp052002

File

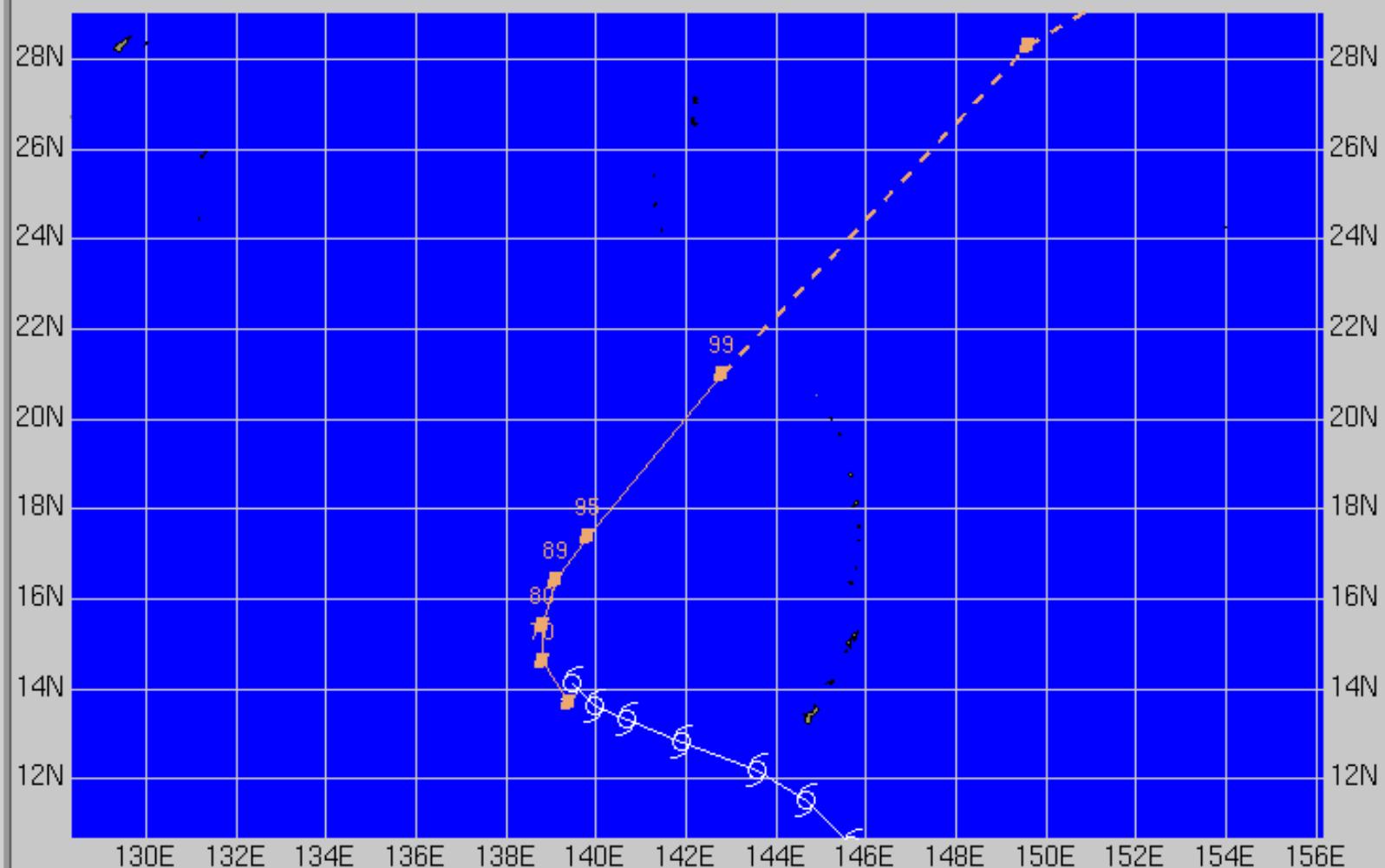
Time Intensity for 05W

Intensity (kts)



ATCF - AOR+ - NONAME wp052002

File Tools Fixes Track Aids Fields Forecast Warnings Graphic TCFA Stats Help



17.2N-131.8E

ATCF Text Window - NONAME wp052002

FileWP0502
05-17-02 12 UTC

TIME (HR)	0	12	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	60	70	80	89	95	99	99	93	78	64	50
V (KT) LAND	60	70	80	89	95	99	99	93	78	64	50

FACTORS RELATED TO THE STIPS FORECASTS

GEN SHEAR (KTS)	6	4	5	8	10	11	15	24	50	57	50
SST (C)	28.7	28.7	28.7	28.6	28.8	28.9	29.0	26.5	23.6	21.5	18.7
POT. INT. (KT)	172	172	172	169	173	173	173	126	89	72	58
200 MB U (KT)	-5	1	9	13	18	18	21	34	54	58	58
200 MB DIVG	72.0	54.0	44.0	61.0	24.0	52.0	29.0	78.0	61.0	48.0	34.0
500-300 MB RH	67	69	72	72	74	71	66	64	44	41	31
LAND (KM)	1533	1467	1485	1544	1649	1681	1552	1308	1166	1365	1554
LAT (DEG N)	14.1	14.6	15.4	16.4	17.4	19.2	21.0	24.6	28.3	31.2	34.1
LONG(DEG E)	139.5	138.8	138.8	139.1	139.8	141.3	142.8	146.2	149.6	154.4	159.2

STORM SPEED/HEADING (KTS/DEG) 4/306

EAST/NORTH STORM MOTION COMPONENTS -3/ 3

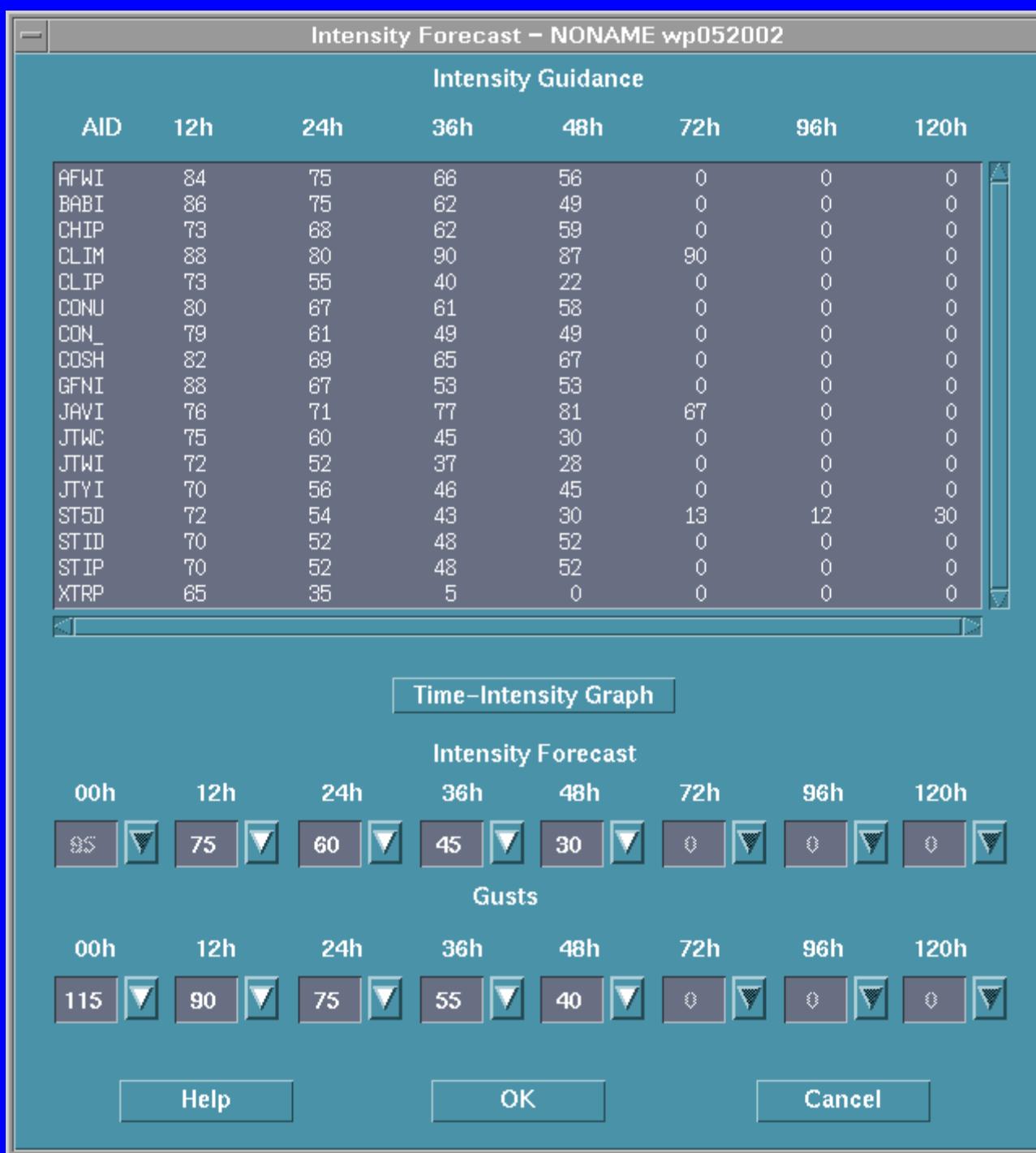
PRESSURE OF STEERING LEVEL (MB) 550

T-12 MAXIMUM WIND (KTS) 50

INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	5.	7.	9.	11.	13.	16.	18.	20.
SST POTENTIAL	4.	9.	12.	14.	15.	15.	7.	-5.	-16.	-26.
VERTICAL SHEAR	1.	4.	7.	10.	12.	13.	13.	10.	7.	5.
PERSISTENCE	3.	3.	3.	2.	1.	0.	0.	0.	-1.	-2.
200 MB DIVG.	0.	0.	1.	0.	-1.	-2.	-1.	-1.	-2.	-4.
500-300 MB RH	0.	1.	2.	3.	4.	4.	3.	2.	2.	1.
ZONAL STORM MOTION	0.	0.	0.	-1.	-2.	-2.	-3.	-3.	-3.	-3.
TOTAL CHANGE	10.	20.	29.	35.	39.	39.	33.	18.	4.	-10.

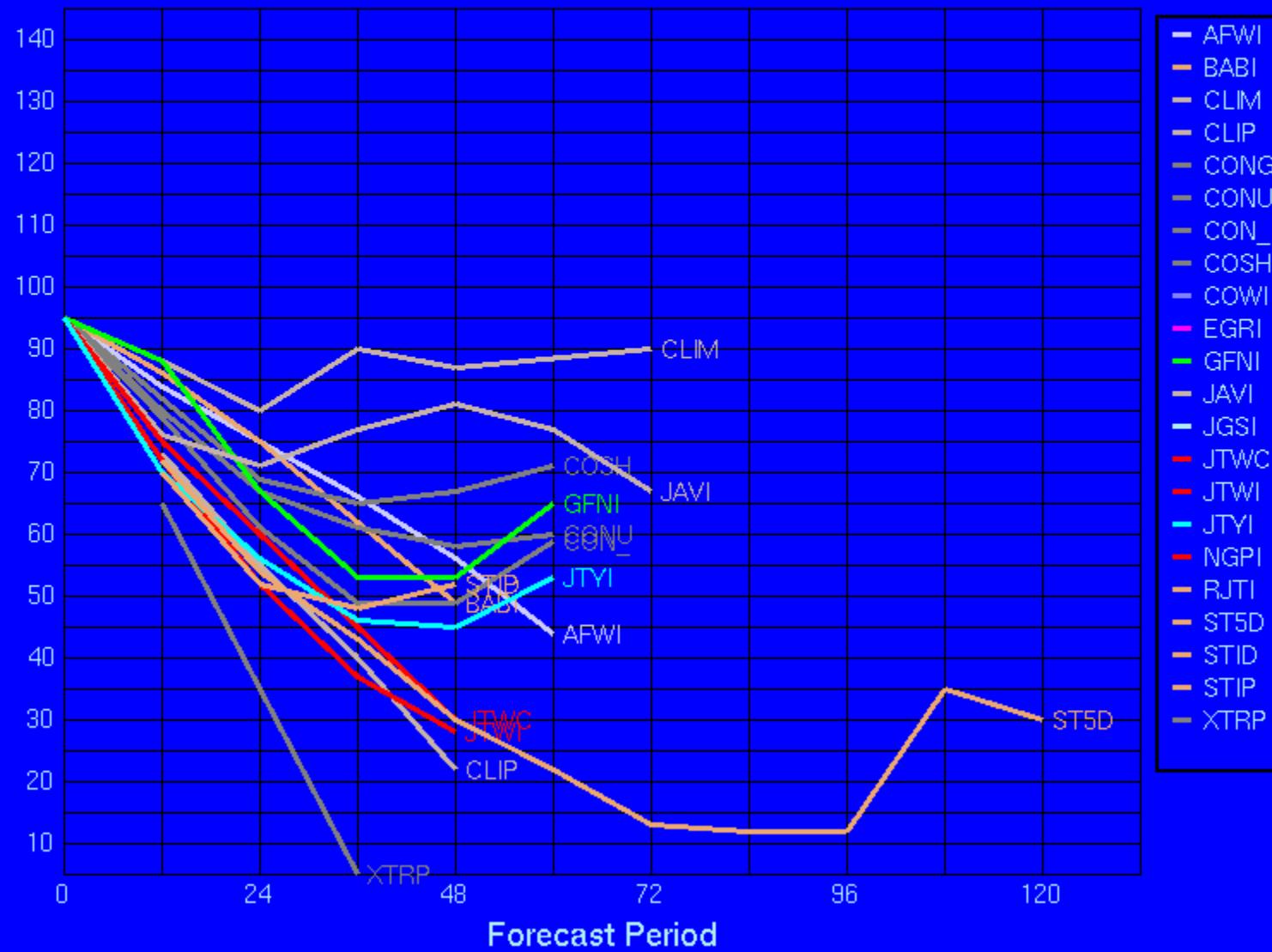
5-20-02
12 UTC
Example

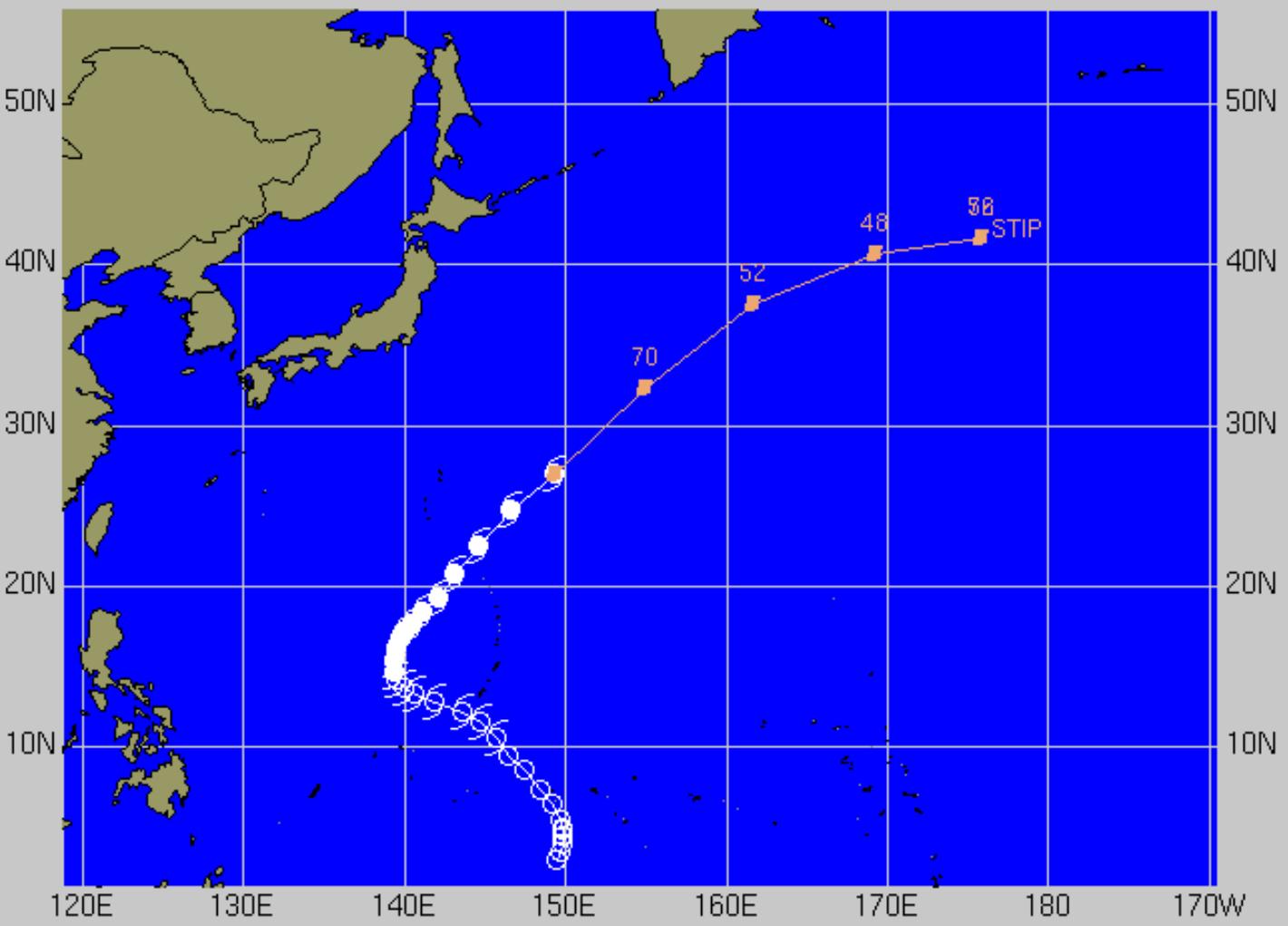


File

Time Intensity for 05W

Intensity (kts)





File

WP0502

05-20-02 12 UTC

TIME (HR)	0	12	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	95	70	52	48	52	N/A	N/A	N/A	N/A	N/A	N/A
V (KT) LAND	95	70	52	48	52	N/A	N/A	N/A	N/A	N/A	N/A

FACTORS RELATED TO THE STIPS FORECASTS

GEN SHEAR(KTS)	33	42	51	51	71	N/A	N/A	N/A	N/A	N/A	N/A
SST (C)	24.5	20.7	15.3	12.4	10.7	N/A	N/A	N/A	N/A	N/A	N/A
POT. INT. (KT)	98	67	49	44	43	N/A	N/A	N/A	N/A	N/A	N/A
200 MB U (KT)	39	47	60	80	93	N/A	N/A	N/A	N/A	N/A	N/A
200 MB DIVG	152.0	177.0	118.0	45.0	40.0	N/A	N/A	N/A	N/A	N/A	N/A
500-300 MB RH	64	65	71	64	54	N/A	N/A	N/A	N/A	N/A	N/A
LAND (KM)	1250	1370	1496	1508	1751	N/A	N/A	N/A	N/A	N/A	N/A
LAT (DEG N)	27.0	32.3	37.5	40.6	41.6	N/A	N/A	N/A	N/A	N/A	N/A
LONG(DEG E)	149.3	155.0	161.7	169.2	175.8	N/A	N/A	N/A	N/A	N/A	N/A

STORM SPEED/HEADING (KTS/DEG) 36/ 43

EAST/NORTH STORM MOTION COMPONENTS 28/ 26

PRESSURE OF STEERING LEVEL (MB) 651

T-12 MAXIMUM WIND (KTS) 125

INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	5.	7.	9.	11.	13.	16.	18.	20.
SST POTENTIAL	-21.	-43.	-55.	-62.	-64.	-65.	-65.	-59.	-54.	-49.
VERTICAL SHEAR	2.	3.	6.	9.	11.	13.	15.	13.	9.	5.
PERSISTENCE	-11.	-14.	-14.	-10.	-6.	-1.	3.	3.	7.	9.
200 MB DIVG.	4.	7.	9.	9.	12.	14.	16.	18.	19.	19.
500-300 MB RH	0.	1.	1.	1.	1.	2.	2.	1.	1.	2.
ZONAL STORM MOTION	0.	0.	1.	3.	6.	7.	8.	8.	9.	10.
TOTAL CHANGE	-25.	-43.	-47.	-43.	-32.	-19.	-8.	0.	8.	15.

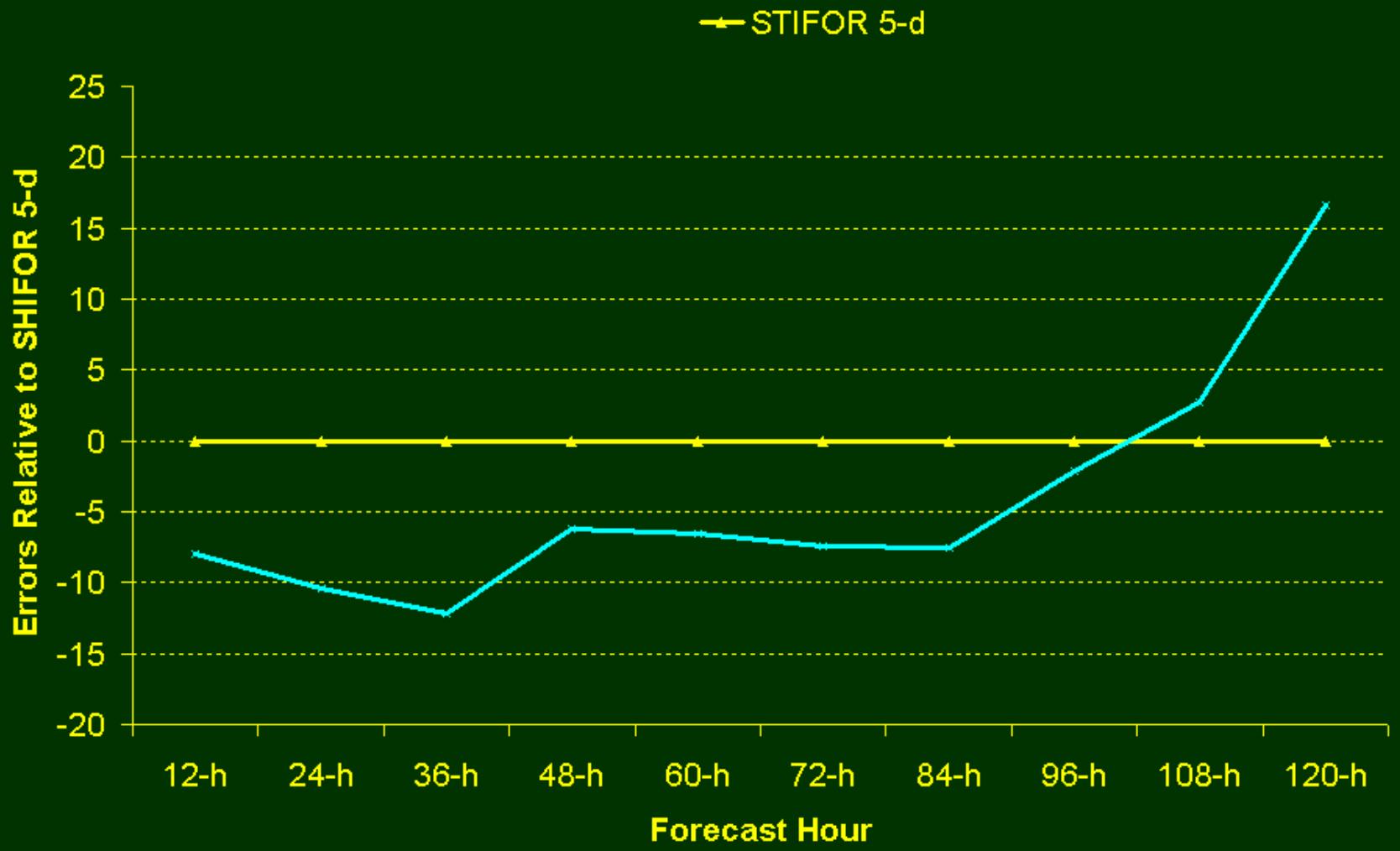
Unfortunately I have no example of a storm that crosses land and decays

Expectations

- Expect to improve upon ST5D by about 10% through 84 hours based upon experience in other basins.
- Graphical and Text output will help the forecaster anticipate changes along the forecast track based upon their own experience.

Projected STIPS Performance

Projected STIPS Performance (Average East Pacific and Atlantic)



Includes depression stag

Shortcomings

- Inaccurate input will adversely affect the forecasts (behind in intensity or large erroneous jumps in intensity, bad track forecasts, timing on landfall)
- Rapid intensification (i.e. 42 mb/d) will not be predicted. Statistical models predict the mean changes and will underestimate rapid fluctuations in intensity.
- STIPS is dependent upon the forecast fields from NOGAPS.
- The inland decay model may cause rapidly weakening storms to decay slower over land (in STID than in the STIPS)

Questions?

* CIRA/NESDIS STATISTICAL TYPHOON INTENSITY PREDICTION SYSTEM (STIPS) *

* WEST PACIFIC 5-DAY FORECASTS *

TESTSTORM 12/18/01 12 UTC

TIME (HR)	0	12	24	36	48	60	72	84	96	108	120
V (KT) NO LAND	55	59	64	68	69	69	66	63	59	52	55
V (KT) LAND	55	59	64	68	69	69	66	63	59	52	55

FACTORS RELATED TO THE STIPS FORECASTS

GEN SHEAR (KTS)	10	11	13	15	19	17	17	14	12	N/A	10
SST (C)	29.6	29.2	28.9	28.7	28.7	28.8	28.6	28.3	28.2	26.2	28.3
POT. INT. (KT)	173	173	173	172	172	173	169	162	160	121	162
200 MB U (KT)	-4	-8	-9	-8	-5	-6	-8	-10	-12	N/A	-10
200 MB DIVG	52.0	17.0	1.0	19.0	20.0	44.0	33.0	38.0	44.0	N/A	70.0
500-300 MB RH	62	58	65	72	74	71	68	71	72	N/A	78
LAND (KM)	2043	1958	1902	1869	1850	1841	1837	1805	1784	1810	1861
LAT (DEG N)	5.7	5.9	6.1	6.8	7.5	8.3	9.1	9.9	10.7	11.9	13.1
LONG(DEG E)	162.0	160.8	159.9	158.7	157.5	156.1	154.7	152.9	151.2	149.1	147.1

STORM SPEED/HEADING (KTS/DEG)	6/280
EAST/NORTH STORM MOTION COMPONENTS	-6/ 1
PRESSURE OF STEERING LEVEL (MB)	633
T-12 MAXIMUM WIND (KTS)	55

INDIVIDUAL CONTRIBUTIONS TO INTENSITY CHANGE

	12	24	36	48	60	72	84	96	108	120
SAMPLE MEAN CHANGE	1.	2.	4.	6.	9.	10.	13.	15.	17.	20.
SST POTENTIAL	4.	10.	14.	17.	18.	18.	16.	13.	6.	5.
VERTICAL SHEAR	0.	0.	-1.	-3.	-6.	-9.	-11.	-12.	-13.	-12.
PERSISTENCE	-1.	-1.	-1.	-1.	0.	0.	1.	1.	1.	2.
200 MB DIVG.	-1.	-2.	-4.	-6.	-7.	-9.	-10.	-11.	-12.	-12.
500-300 MB RH	0.	1.	1.	2.	3.	3.	3.	3.	4.	4.
ZONAL STORM MOTION	0.	0.	0.	-1.	-3.	-4.	-5.	-5.	-6.	-7.
TOTAL CHANGE	4.	9.	13.	14.	14.	11.	8.	4.	-3.	0.